

Parametric Mission Cost Model - Overview



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PMCM - Modeling Team

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PMCM Status - Outline

- 1 - Why build yet another model?
- 2- Model objectives
- 2 - Current model status (including history)
- 3 - Modeling approach
- 4 - Database
- 5 - Statistical basis
- 6 - Model summary - WBS, CERs
- 7 - Validation procedure
- 8 - Current & future activities

Why build yet another model?

The Old Days -- " 1990

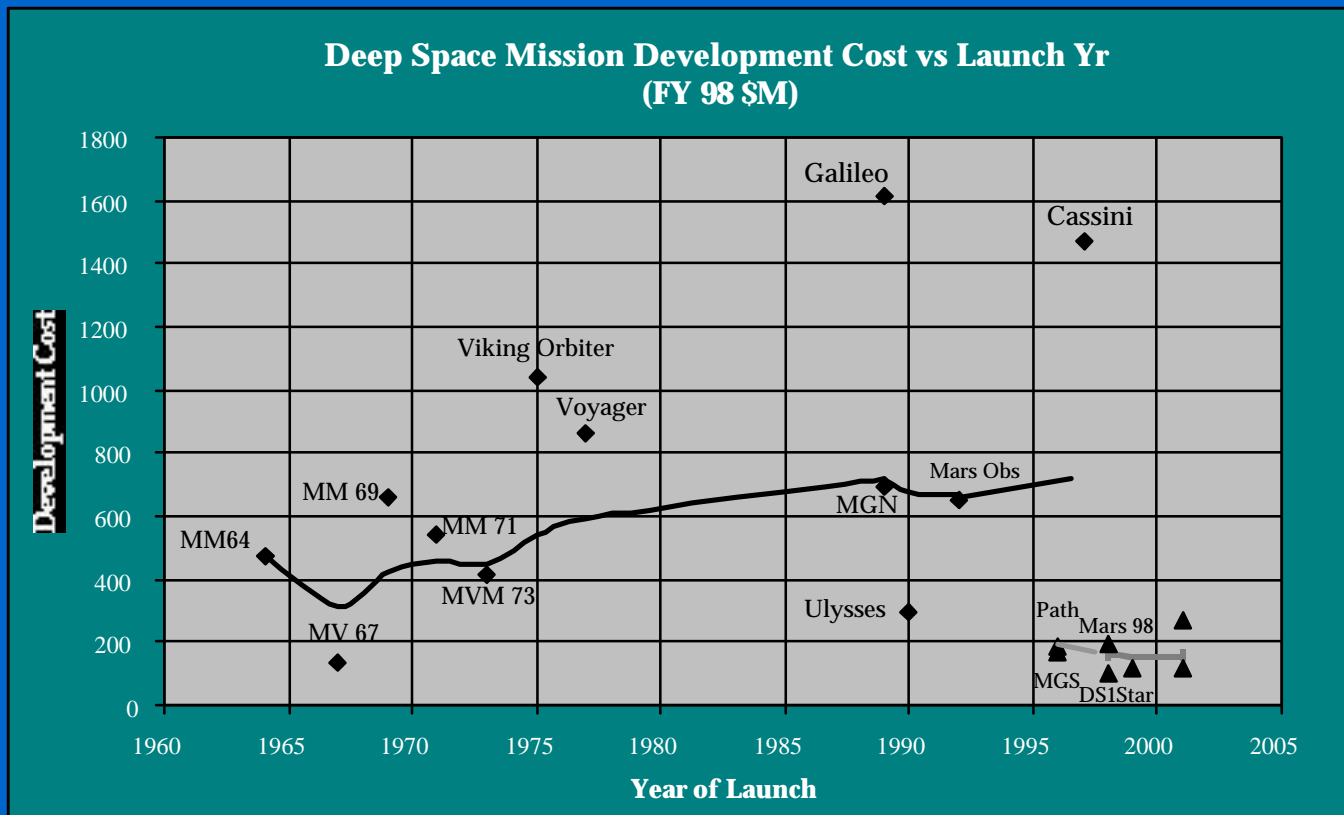
- Non-competitive proposals (average cost per project " \$1B without L/V)
- 3-5 proposals (design/cost) per year
- No faster, better, cheaper
- No real cost caps
- Old cost models built to old mission style
- Questionable statistical validation of old models.



Today -- " 2000

- Competitive proposals - i.e., Discovery, SMEX, ESSP, etc (average cost " \$75 - 300M with L/V)
- 60-100 proposals (design/cost) per year
- Faster, better, cheaper
- Real cost caps
- Defendable, accurate early cost estimates are very important -
 - Modeling used as grass roots check & when detailed design data is not available
 - Validation necessary
- Old cost models no longer applicable
- Outside cost models do not fit many JPL missions very well:
 - No real deep space cost data beyond Mars
 - JPL has missions to Mercury, Jupiter comets, Pluto, rovers, landers, sample return.

Why build yet another model?



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Model Objectives

- The cost estimation community needs a model that:
 - Is fast, accurate, & consistent
 - Has a minimum of subjective inputs
 - Can be used for cost/performance trade analysis
 - Is defensible (approved by peers, good statistical basis, based on actual mission costs)
 - Can be used to identify proposal/design tall pole issues,
 - Can be used early in proposal cycle to identify proposal areas of strength & weakness, and as a sanity check on proposal cost estimates
 - Can be successfully integrated with other automated design tools
 - Can be used as a surrogate when proposal teams are over committed

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Model Status - History

- PMCM (version 1) developed in 1997,8
 - Includes instrument model, S/C bus model, secondary CER models, future automated development process assumptions
 - In use for nearly 2 years including Team X, Discovery 98 - Step 1 proposals
- Instrument model developed in 1996 (updated 98)
 - Based on 95 actual flown instruments
 - In use on JPL design teams (including Team X)
- Secondary CER models (project office, ATLO, MA&E) - originally developed in 1996 to provide total project life cycle cost

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Current Model Status

- PMCM (version 2) completed in 1999. Includes major updates to S/C bus & mission operations models.
- Model reflects JPL's new automated design process.
- Successfully implemented with other JPL automated design tools.
- The model is close to obtaining its objectives.
- The model is used by JPL's proposal design team.
- Year 2000 update is in progress. This includes a formal validation



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Modeling Approach

- PMCM (version 2) CER update process
 - Collected, reviewed, & verified data
 - Identified key cost drivers (design parameters)
 - Developed CERs for each subsystem based on all available parameters (cost drivers)
 - Reviewed results with Team X subsystem engineers
 - Revised & developed system & mission cost models
 - Encoded model in Excel worksheet (visual basic language)
 - Model validation currently on-going

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Modeling Approach

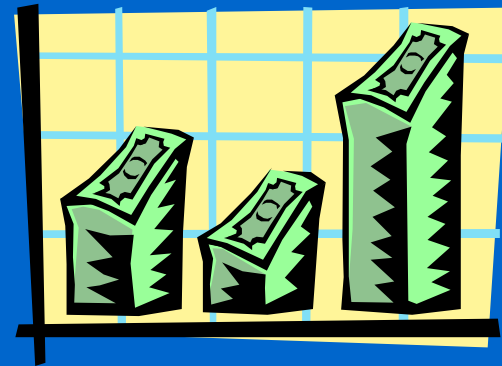


- Philosophy
 - Avoid mass as a dependent variable
 - Include key design parameters that are likely to be known in early stages of design (high level requirements)
 - Keep model as linear as possible to make parameter interpretation intuitive
 - Use of objective cost drivers, while minimizing use of subjective variables

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Database

- Identified 55 potential data records & collected > 200 design parameters (e.g., high level parts lists, tech type, pointing knowledge, BOL power, etc.).
- Deleted incomplete and duplicate records.
- This yielded 43 complete data records based on Team X studies completed from March 97-October 98 that assumed JPL's new FBC development process.



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Statistical Basis

- While significant outliers were identified & removed, the objective was to keep data records as consistent as possible across subsystems
- Used multivariate linear regression & selected cost variables based on causal engineering relationships &:
 - F-ratio > 10 (1% for 10 degrees of freedom), $\text{adj } R^2 > 75\%$, student t-ratio > 1.95 (5%)
 - Dropped variables whose direction was inconsistent with engineering principles
 - Kept some variables with low t-ratios if :
 - Variable was a major design parameter
 - Coefficient was consistent with expert engineering judgement

Model Summary - WBS

Work Breakdown Structure (WBS)	Model Form
Total Project Costs (\$M)	
10 Project Management	
1.1 Project Management & Staff	%
1.2 Launch Ramp	List
1.3 Preliminary Production Approval	List
1.4 Education & Public Outreach	%
20 Science Team	WF
30 Mission Design & Project Engineering	%
40 Instruments	
4.1 Payload Management	%
4.2 Payload Engineering	%
4.3 Instrument Burden & Fees	%
4.4 Instrument I	CER
50 Spacecraft	
5.1 Primary Spacecraft	
5.2 Stage 2	
60 A TLO	CER
70 Mission Operations & Development	
80 Resources	%
90 Launch Vehicle	List
100 Upgrades & SRM	List

Work Breakdown Structure (WBS)	Model Form
50 Spacecraft	
5.1 Primary Spacecraft	
5.1.1 S/C Bus Management	%
5.1.2 S/C Bus System Engineering	%
5.1.3 S/C Bus Ride & Fee	%
5.1.4 Attitude Control Subsystem	CER
5.1.5 Command & Data Handling Subsystem	CER
5.1.6 Power Subsystem	CER
5.1.7 Propulsion Subsystem	CER
5.1.8 Structure & Mechanisms Subsystem	CER
5.1.9 Telecommunications Subsystem	CER
5.1.10 Thermal Subsystem	CER
5.1.11 Mechanic Build-Up	CER
5.2 Stage 2	
70 Mission Operations & Development	
7.1 Command, Telemetry & Mission Data Management	CER
7.2 Navigation	CER
7.3 Experiment Flight Data Products	CER
7.4 Sequence Engineering, Science Observation Planning, Ground Communications & Information	CER
7.5 Project Provided Tasks	CER
7.6 Attenuation Reg	CER

Model Structure - CERs

Cost Element	Statistically Significant Cost Model Inputs
ACCS ($R^2 = 88.1$, F-ratio = 45.3)	Pointing Knowledge New Design Design Copy # of ASCHW Types # of Auctors
CDH ($R^2 = 62.3$, F-ratio = 15.9)	Nonautonomy Number of Cards Processor < 5ipsm
Power ($R^2 = 95.7$, F-ratio = 129)	Array Area Cell Type Number of GPHS Battery Only
Pulsions (CER# 1) ($R^2 = 72.7$, F-ratio = 27.7)	Cdd Gas Hydrazine HAMTEAN Bi-Propellant Model SEP
Pulsions (CER# 2) ($R^2 = 81.6$, F-ratio = 218)	Ln (Total Impulse)
Structures & Mechanisms ($R^2 = 84.4$, F-ratio = 109)	# of Mechanism Types # of Mechanisms
Thermal Control ($R^2 = 83.0$, F-ratio = 47.3)	Distribution - Sun/Mercury Launch Mass # of Instruments Distribution Pressure

Cost Element	Statistically Significant Cost Model Inputs
Telecommunications ($R^2 = 89.0$, F-ratio = 32.3)	Ln (Dowlink Data Rate) Antenna Diameter Range (SC-Earth) Optical Secomrta UHF Secomrta Xband Mission Class Subsystem Redundancy
Mechanical Build-Up ($R^2 = 82.2$, F-ratio = 158)	Spacecraft Dry Mass
ATLO (Engineering Algorithm)	Total of Subsystem Costs # of Instruments # of Spacecraft Elements
GDS/MOS (Engineering Algorithm - TMOPricing Algorithms)	# of Instruments Satellite Tour Length Acrobatic Length Target Body Orientation Cruise Length Phase AB Length Phase C/D Length DSN Schedule (# Weeks, Passes/Week Hours/Pass, Antenna)

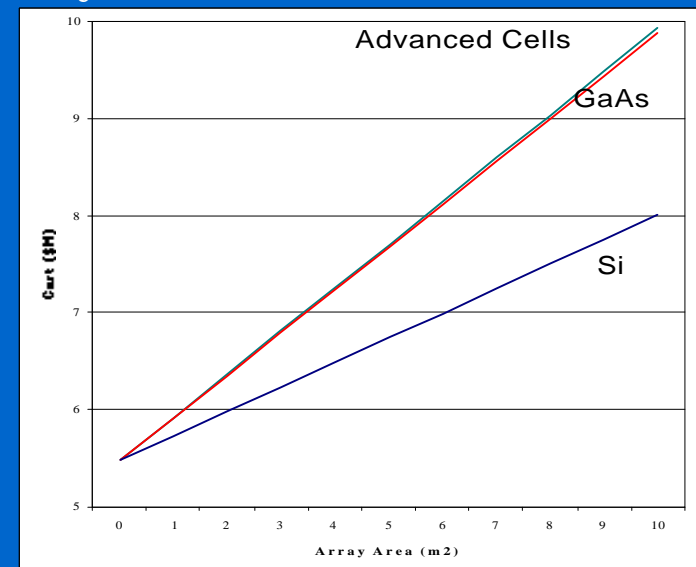
Model Summary - Example CER (Power)



- For each element of the power subsystem (power generation, energy storage, electronics), collected data on technology used and size of the element.
- Data was also collected on key system parameters (thermal environment, radiation total dose), mass by element, & cost by element - total of 30 exogenous variables.
- Analyzed linear & log-linear forms as well as interactions between size and tech type
- Developed two models based on (1) array area and (2) beginning of life power
- Reviewed by Team X power subsystem engineers
- 2 outliers excluded -- unusual technologies (CIS array, thermal-mech-elec conversion)

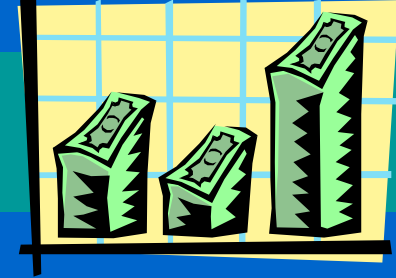
Power Subsystem CER ($R^2 = 95.7\%$, F-ratio = 129)

Variable	Coefficient	t-ratio	Significance
Constant	\$5,477 K	6.25	< 0.0001
Battery Only	- \$4,149 K	-1.77	0.0887
Array Area (m ²) – Si	\$ 253 K	4.14	0.0004
Array Area (m ²) – GaAs	\$ 440 K	4.9	< 0.0001
Array Area (m ²) – Adv. Cells	\$ 445 K	22.8	< 0.0001
Number of GPHS	\$4,854 K	13.7	< 0.0001



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Model Summary



- PMCM (version 2) has complete high level WBS containing " 50 CERs. There were 15 new CERs in 1999.
- It produces a breakdown of life cycle cost results by phase including:
 - Formulation
 - Implementation
 - Operations
- Out of 200 design parameters identified & tested, 47 were found significant

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PMCM Validation & Test

- Review model structure (replicates project WBS)
- Review subsystem CER's with pertinent JPL engineers
- Tested version 1 vs. Discovery 98 proposals
- Currently testing version 2 & version 1 vs. actual missions/winning step 2 proposals (Genesis, Stardust, DS-1, MGS, Inside Jupiter, Deep Impact, Mars Pathfinder, Cloudsat, Cassini, Mars 98 (Orbiter & Lander))
- Peer review board evaluation



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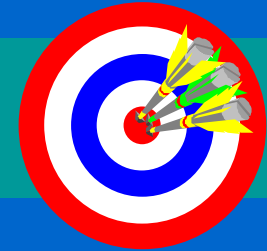
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PMCM Validation & Test

- Model structure replicates Team X design process and uses Team X WBS to determine total project cost.
- Project structure/flow that is modeled has been reviewed by Team X engineers and Team X customers over the last 5 years.
- Individual CER's have been reviewed & verified with pertinent JPL subsystem engineers.

PMCM Validation & Test



Disc 98-Step 1 JPL Proposals (FY 98 \$M)

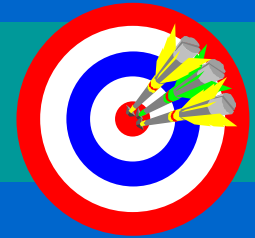
	Proposal Grass Roots Costs	PMCM (ver 1) Total Project Cost	±%
Deep Impact	204	254	25%
Gulliver	264	221	-16%
Hermes	267	301	13%
Hummingbird	260	249	-4%
Impact	151	234	55%
Inside Jupiter	227	200	-12%
Janus	239	252	5%
Kitty Hawk	134	150	12%
Lunar Star	111	111	0%
MBAR	240	271	13%
MUADE	125	138	11%
New World Exp	267	269	1%
Quicksilver	276	287	4%
Vesat	191	212	11%
VEVA	269	242	-10%

- Version 1 did quite well (13 of 15 within $\pm 20\%$).

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PMCM Validation & Test



Validation of Version 2 - Test Cases vs Actuals & Step 2 Proposal Costs (FY 99 \$M)

Mission	Actual Cost	Ver. 1	±%	Ver. 2	±%
DS-1	195.4	207.0	5.9%	203.8	4.3%
Genesis	210.2	218.4	3.9%	221.7	5.5%
Stardust	201.6	178.5	-11.5%	187.9	-6.8%
MGS	229.3	260.6	13.7%	249.7	8.9%
Inside Jupiter	269.0	255.6	-5.0%	227.5	-15.4%
Deep Impact	243.0	324.1	33.4%	286.8	18.0%

- Test case results look good
 - Version 1 $< \pm 20\%$ on 5 of 6 cases (a little better than Disc 98 - Step 1)
 - Version 2 $< \pm 20\%$ on all 6 cases
 - “Actuals” range is -7% to +9% -- closer fit than Version 1.
 - 5 missions are being added

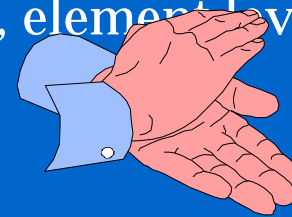
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Future Work on PMCI



- **Areas we are addressing in FY 2000 and in the near future**
 - Data set is being updated (current data is " 1 year old)
 - Detailed SW cost algorithm being developed
 - Secondary CER's need review (i.e., project office, MA&E, sys eng)
 - Participating within advanced PDC design team
 - Instrument model to be updated (current model is 2 yrs old)
 - Documentation started
 - Risk, uncertainty, factors for new technologies
 - Schedule vs. cost algorithm
 - Probabilistic cost estimating tool
 - To better meet customer requirements, other versions of model are needed (simplified version for earlier use, element level, etc.)



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